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THESIS

OBSERVATIONS OF OCEAN AMBIENT NOISE (10 HZ TO 10 KHZ) AT THE SITE OF A FORMER NAVY LISTENING STATION TO THE WEST OF POINT SUR, CALIFORNIA, FROM JANUARY TO JULY OF 2007

by

Paul Cocker

June 2008

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13. ABSTRACT (maximum 200 words)

Ocean acoustic recordings were obtained from January through June of 2007 at the site of a former Unites States Navy listening station to the west of Point Sur, California. These data were analyzed to determine the characteristics of the ambient acoustic noise. Direct comparisons to previous studies conducted at the same location revealed a near identical match of the pressure spectrum level in the 50 to 120 Hz frequency band to a 1994-2001 study. Comparison to a 1963-1965 study revealed a 3 to 5 dB increase in ambient noise over the 60 to 300 Hz frequency band. As expected, relating ambient noise to wind speed revealed a significant (correlation coefficient greater than 0.5) correlation between 400 Hz and 10 kHz with a maximum correlation coefficient of 0.78 near 2 kHz. Comparing shipping data from San Francisco and Los Angeles-Long Beach ports to ambient noise in the 10 to 1000 Hz band revealed obvious patterns in the relationship of the number of ships arriving or departing each day and noise level. Due to its proximity, the San Francisco shipping data had a greater effect on the ambient noise level at Point Sur. The largest value of the correlation coefficient between ambient noise and shipping traffic was 0.55 and occurred at 700 Hz.

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Ocean acoustic recordings were obtained from January through June of 2007 at the site of a former Unites States Navy listening station to the west of Point Sur, California. These data were analyzed to determine the characteristics of the ambient acoustic noise. Direct comparisons to previous studies conducted at the same location revealed a near identical match of the pressure spectrum level in the 50 to 120 Hz frequency band to a 1994-2001 study. Comparison to a 1963-1965 study revealed a 3 to 5 dB increase in ambient noise over the 60 to 300 Hz frequency band. As expected, relating ambient noise to wind speed revealed a significant (correlation coefficient greater than 0.5) correlation between 400 Hz and 10 kHz with a maximum correlation coefficient of 0.78 near 2 kHz. Comparing shipping data from San Francisco and Los Angeles-Long Beach ports to ambient noise in the 10 to 1000 Hz band revealed obvious patterns in the relationship of the number of ships arriving or departing each day and noise level. Due to its proximity, the San Francisco shipping data had a greater effect on the ambient noise level at Point Sur. The largest value of the correlation coefficient between ambient noise and shipping traffic was 0.55 and occurred at 700 Hz.

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I. INTRODUCTION

A. BACKGROUND

Since the proliferation of the submarine in World War I, the characteristics of sound in the ocean have been a priority to naval forces. As today’s approach to Anti-Submarine Warfare (ASW) continues to shift toward littoral regions, detecting very quiet signals of modern diesel-electric and air-independent propulsion submarines in highly variable and noisy environments is the challenge. Environmental factors such as wind, rain, sea state, and tectonic activity as well as anthropogenic and biological sources all contribute to noise in the ocean. In order to effectively conduct ASW missions, it is imperative to be able to accurately predict the background noise levels in the area of operation. To optimize sensor performance it is necessary to have the ability to forecast real-time noise variability based on measurable parameters such as wind speed, sea state, and shipping activity. The noise level predictions that are currently in operational use are based on results and trends derived from historical data.

B. OBJECTIVES

As new technologies and sensor designs become available, it is important to both validate performance and determine applicability for improving military performance. The High-Frequency Autonomous Recording Package (HARP) was developed by the Scripps Institution of Oceanography to study marine mammals. Due to its high data capacity (1.92

TB) and broad frequency range (10-200,000 Hz), the HARP is well suited for studies involving characteristics and trends in ocean ambient noise. The Naval Postgraduate School has deployed a HARP at the location of a U.S. Navy Sound Surveillance System (SOSUS) receiver where ambient noise measurements have been conducted in the past. This allows for direct comparison to previous studies. Since most of the previous studies at this site were at lower frequencies (<500 Hz), it is also desirable to determine if acoustic trends can be extended to higher frequencies recorded by the HARP.

The objective of this study is to also compare wind related ocean noise recorded by the HARP to the widely accepted Wenz curves derived in 1962, as well as performing correlations of wind speed and ocean noise at various frequencies up to 10 kHz. Additionally, diel patterns of ocean noise are of interest. From a tactical ASW standpoint, it is important to understand daily patterns of noise, whether from meteorological, biological, or other sources. Finally, relating port activity, or shipping density, to ocean noise is of utmost importance to ASW operations and will be addressed in this study.

II. DATA COLLECTION

A. HIGH-FREQUENCY ACOUSTIC RECORDING PACKAGE (HARP)

1. Specifications

The HARP allows for sampling rate of up to 200 kHz and 1.92 TB of data storage per instrument deployment. At a sampling rate of 200 kHz, 55 days of continuous recording is possible, and about one year of continuous recording is available at 20 kHz (Wiggins and Hildebrand, 2007).

2. Applications in this Study

The Naval Postgraduate School has employed two HARPs in a rotating deployment cycle since October 2006. The HARP mooring was co-located with the now decommissioned U.S. Navy Sound Surveillance System (SOSUS) receiver, approximately 40 km west of Point Sur, California (36º 17.95′ N, 122º 23.63′ W, 1402 m depth).

A schematic diagram of the mooring is shown in Figure 1. The mooring was anchored with one train wheel which was attached by chain to dual acoustic releases. Above the releases, four glass balls were attached by chain to provide flotation. The HARP components with the exception of the hydrophone were connected to the glass balls by jacketed wire rope. The components were packed in high-density polyethylene tubes, which in turn were mounted to a 1.6 m long by .57 m diameter titanium frame. The hydrophone extended 2.8 meters above the frame and was fixed to the jacketed wire rope by two vibration isolators. Higher on the mooring line, a current meter was affixed to the rope and then the 40 inch diameter mooring buoy was connected by chain. The total length of the mooring was 28 meters and the hydrophone was located 19 meters above the sea floor.

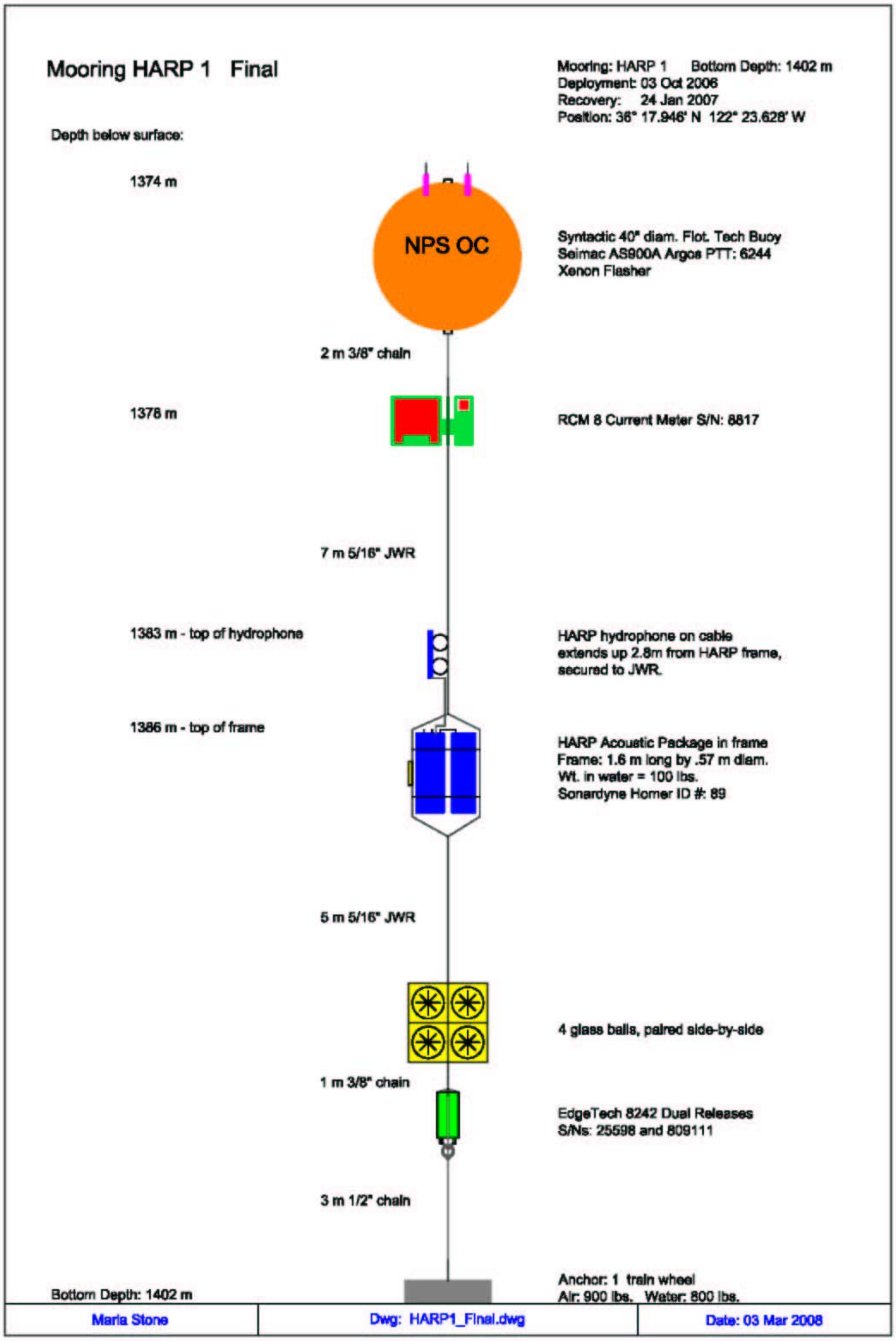

Figure 1. HARP Mooring Diagram

The data used in this study came from the second deployment. The data from the first deployment would have been analyzed as well, but due to equipment problems, most of the records were unusable. The first deployment occurred from 03 October 2006 to 24 January 2007 and the second occurred from 24 January to 17 July 2007. For both deployments, the HARP used a recording cycle of five minutes of continuous recording at 200 kHz and ten minutes off. Each five minute recording period was stored to disk in four 75 second segments. The data was then down-sampled by a factor of ten, providing a frequency range of 0-10 kHz for analysis.

Due to system noise, which was prevalent in the recorded data, a ten second period near the end of each 75 second segment was chosen for analysis. It was obvious when played audibly that most of the system noise was caused by the disk drives as they activated in the disk writing process. This noise occurred in three out of four of the 75 second recorded segments. This noise began as a momentary broadband signal and then settled at around 1200 Hz. There was also persistent system noise at around 3800 Hz and 7800 Hz which was of unknown origin (Figure 2).

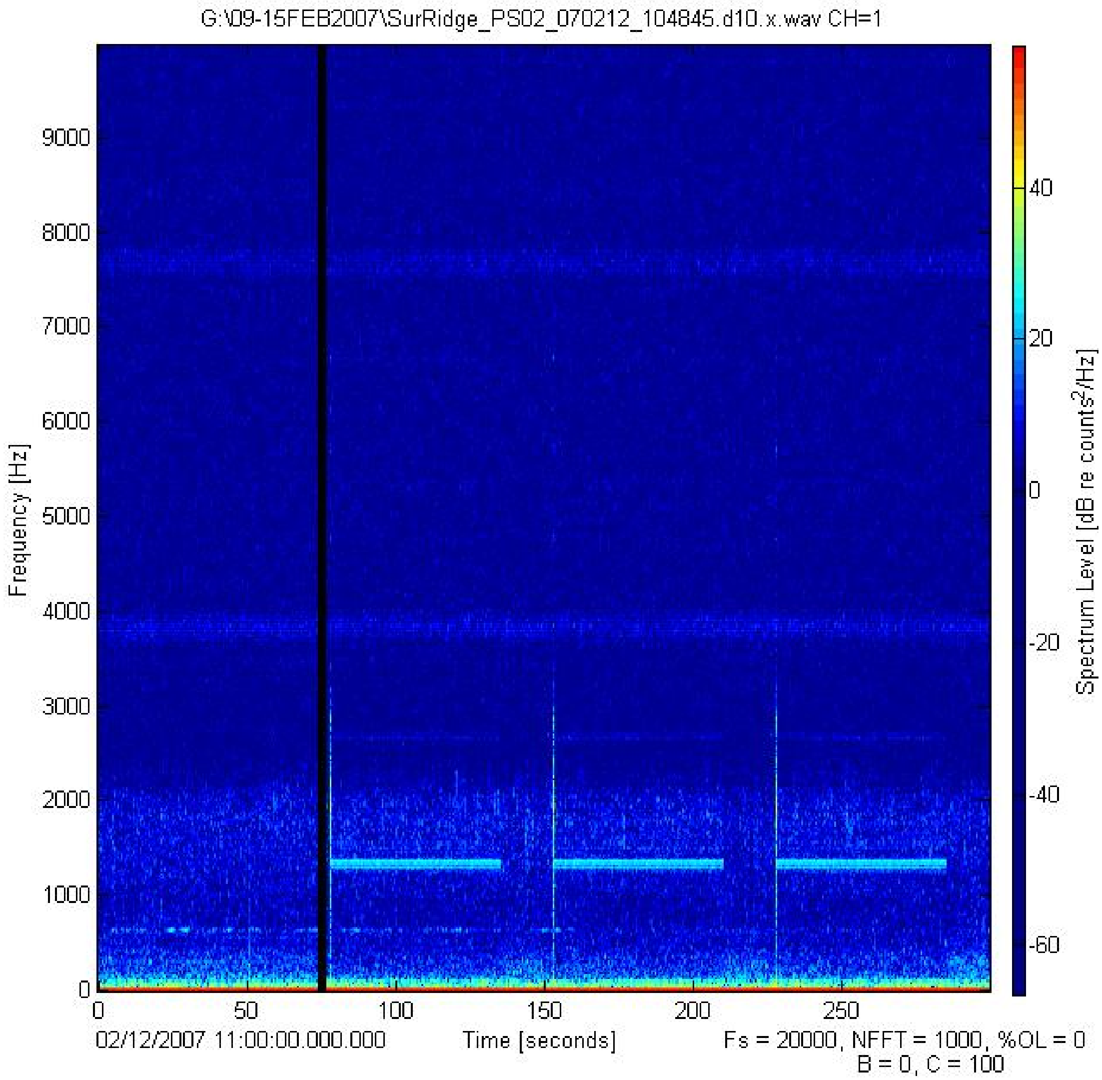

Figure 2. A sample HARP recording spectrograph depicting four 75 second recording segments. System noise is prevalent around 3800 Hz and 7800 Hz. There is also periodic system noise caused by the disk writing process which begins as a broadband spike and settles near 1200 Hz. The data utilized for analysis came from a 10 second portion of recording that follows each disk noise event.

The amplitude of the noise data was converted to a power spectral density using Welch's method. The length of the fast Fourier transforms (FFT) was 512 which resulted in 39.06 Hz frequency bins. A transfer function which contained the hydrophone calibration data was then applied. The resultant ambient sound data had units of dB re 1 $\mu Pa^2/Hz$. The same week of each month (days 9-15) was picked for analysis.

B. METEOROLOGICAL DATA

All meteorological data came from the National Oceanic and Atmospheric Administration’s (NOAA) National Data Buoy Center (NDBC) buoy 46042. The buoy is located approximately 50 km north of the HARP mooring (36º 45.18′ N, 122º 25.35′ W) (Figure 3). Wind speed observations at ten minute intervals were averaged to obtain hourly values. Sea surface temperature, air temperature, and atmospheric pressure, which were used in calculations of wind stress, were hourly observations.

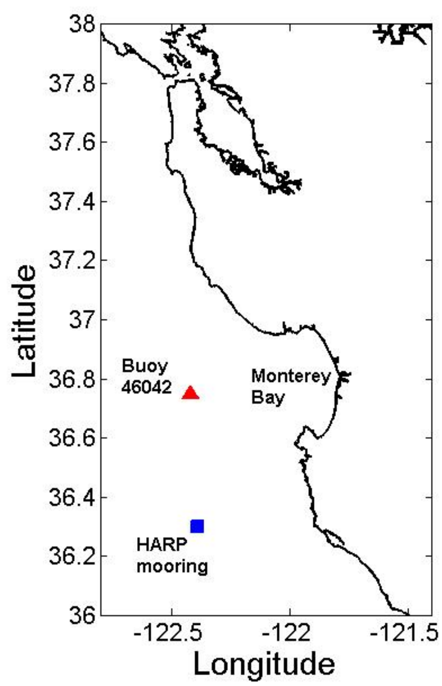

Figure 3. Locations of the HARP mooring and NOAA’s NDBC buoy 46042

C. SHIP TRAFFIC DATA

Shipping traffic information was obtained from the United States Coast Guard’s Vessel Traffic Service (VTS) for both the San Francisco Bay and Los Angeles-Long Beach areas. Arrivals and departures for each day were grouped together based on the direction of travel. There were considered to be three routes available to ships entering or leaving port; north, south, and west. Since the VTS data contained the previous and next ports of call, separating travel directions was straightforward. For comparisons with ocean noise, the ship traffic data containing San Francisco arrivals and departures to the south and Los Angeles-Long Beach arrivals and departures to the north were used.

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III. ANALYSIS AND RESULTS

A. COMPARISONS TO PAST WORK AT SAME LOCATION

Between January 1963 and December 1965, data were collected by Wenz (1969) using the SOSUS receiver at Point Sur. Andrew et al. (2002) analyzed data collected by the same hydrophone array, spanning the time period from June 1994 to January 2001. In order to edit out “noise transients”, likely due to nearby ships, both data sets were processed in the same way. Three consecutive levels were estimated over 10 minutes at the top of every hour. If any of the three-way level comparisons exceeded ±3 dB, the three levels were discarded; otherwise the three levels were averaged and retained (Andrew et al. 2002).

The HARP data were averaged without the exclusion of any transients. The comparisons are shown in Figure 4. Below 120 Hz, the recorded noise from the HARP and the SOSUS array from 1994 to 2001 are virtually identical. Above 200 Hz, the HARP data more closely follow the results from 1963 to 1965 and was consistently 2-3 dB greater than the Wenz results between 80 and 300 Hz.

McDonald et al. (2006) reported that the Lloyd’s Register indicated a doubling of the world’s commercial fleet over the 38 years between 1965 and 2003; from 41,865 vessels to 89,899 vessels. Assuming an incoherent combination of noise from individual ships, noise would follow a 10*log(N) increase. This is suggested as a reasonable explanation for HARP data being 2-3 dB higher than Wenz between 80 and 300 Hz.

The difference between the Andrew et al. (2002) and Wenz (1969) results for frequencies greater than 120 Hz was as large as 9 dB. Andrew et al. were unable to provide a reason for the increase in ambient acoustic noise at these frequencies (> 120 Hz). Therefore the reason for the departure of the HARP and Andrew et al. (2002) measurements at 120 Hz is not known but may be due to differences in the equipment used.

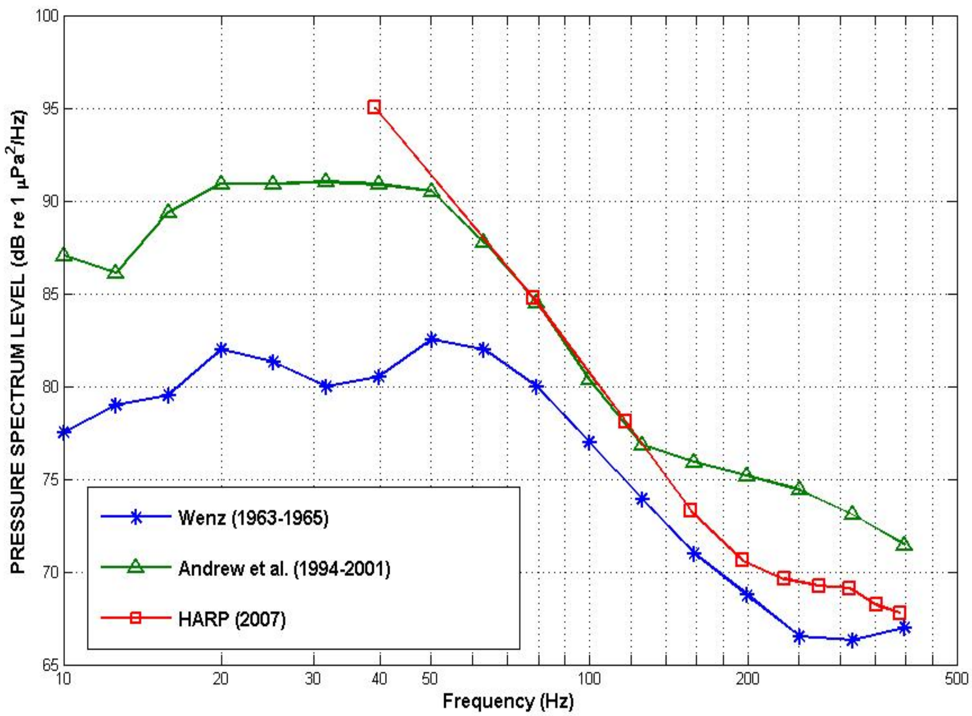

Figure 4. Comparison of averaged ambient noise spectrum levels at Point Sur for three different time periods.

B. AMBIENT NOISE AND WIND SPEED RELATIONSHIPS

1. Correlation to Wind Speed

Wind noise contributes significantly to ocean ambient noise. To determine the frequencies most affected by wind noise, the normalized correlation between the wind speed and ocean noise (both averaged over one hour) was computed for various frequencies using data from the second HARP deployment. Figures 5 and 6 show the correlation coefficient plotted as a function of lag time. The ambient noise spectrum is highly variable in the 10-500 Hz band (Wenz 1972) and is most affected by ocean traffic and seismic activity. It is apparent from Figure 5 that ocean noise had a very weak correlation to wind speed at low frequencies, and the correlation increases with frequency. McDonald et al. (2006) hypothesized that the breakpoint between shipping and wind dominated noise has shifted well above the 200 Hz breakpoint presented by Wenz (1969). McDonald et al. (2006) attributed this increase in the breakpoint frequency to a near quadrupling of the gross tonnage of shipping at sea between 1969 and 2003 and the increased time each ship spends at sea due to quicker port turn-around. Figure 5 supports McDonald et al. (2006) as the correlation coefficient does not exceed 0.5 until frequencies reach about 400 Hz.

The frequencies below 1000 Hz exhibited maxima in the correlation coefficient at lag times of 3-5 hours. Since this phenomena is not apparent in the data at higher frequencies, these maxima are likely a result of ship traffic. The lower bands (10 Hz to 1000 Hz) of the sound spectrum are typically dominated by ship noise and the deployment site experiences a steady flow of traffic. It is hypothesized that the data contained a pattern of ship traffic which resulted in the maxima at the lag times observed in Figure 5.

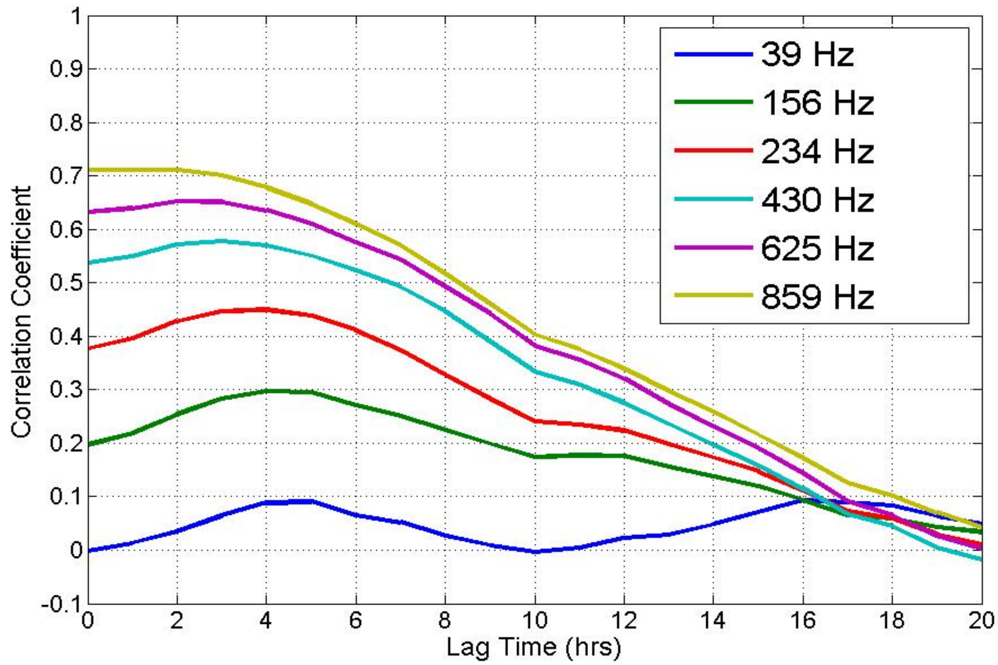

Figure 5. Correlation coefficient of ocean noise and wind speed at frequencies below 1000 Hz. Lag time is wind leading ocean noise.

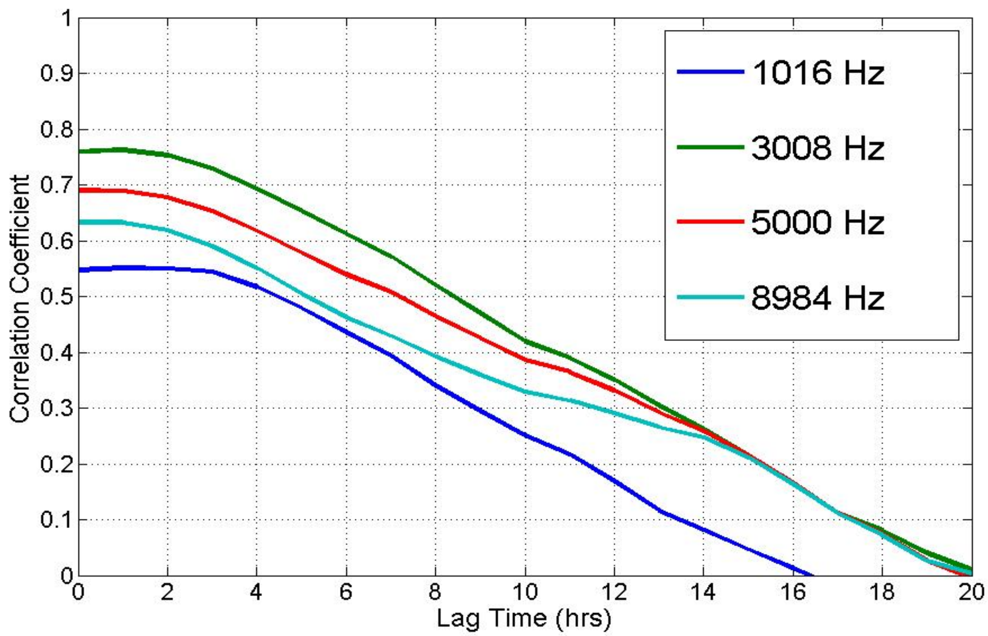

Figure 6. Correlation coefficient of ocean noise and wind speed at frequencies between 1 kHz and 10 kHz. Lag time is wind leading ocean noise.

Figure 7 shows that at frequencies above 80 Hz, the correlation coefficient increased with frequency to about 2 kHz. At frequencies above 2 kHz, the correlation coefficient decreased as frequency increased. This may be explained by reduced hydrophone sensitivity in the higher frequency range which is discussed in the next section.

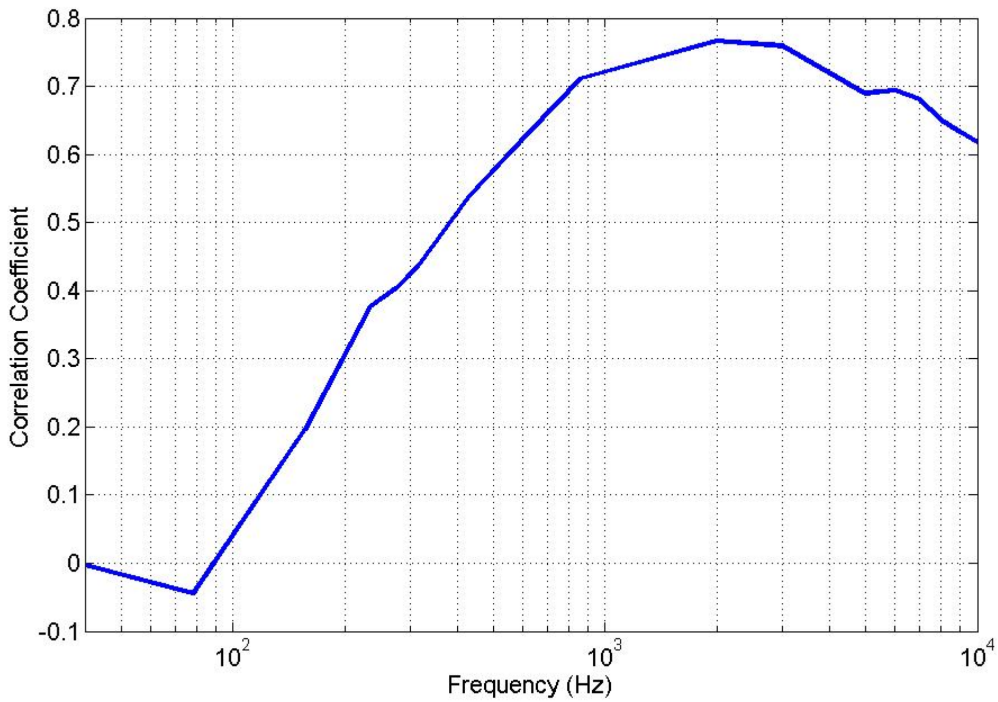

Figure 7. Correlation coefficient of wind speed and ambient noise at zero lag as a function of frequency.

2. Ocean Noise as a Function of Sea State

The hourly averaged ocean noise, from the second HARP deployment, corresponding to various sea states is plotted with the Wenz (1962) curves in Figure 8. In general, the HARP data showed an anticipated separation in noise levels for different sea states. Between a range of 500 Hz to 2 kHz, the separation between the sea states was only slightly less than that of Wenz (1962). At frequencies below 700 Hz, the HARP recorded noise levels tended to increase as frequency decreased. This can be explained by the effect of ship traffic noise which dominated at frequencies between 10 Hz and 1000 Hz. At frequencies higher than 3 kHz, the recorded noise for the various sea states tended to be above predicted values and converged upon one another. While still within the bounds presented by Wenz (1962) (illustrated by the thick black lines in Figure 8), it was not expected.

The reason for the observed increase in ambient noise for frequencies greater than 3 Hz could possibly be attributed to hydrophone sensitivity. The hydrophone included two stages of signal conditioning, one for the frequency band from 10 Hz to 2000 Hz and the other from 1000 Hz to 100,000 Hz (Wiggins and Hildebrand 2007). The apparent local maxima in the HARP data curves near 2 kHz in Figure 8 coincide with the crossover frequency for these two stages of conditioning. Since the design is relatively new and still in the developmental stages, calibration experiments to validate the sensitivity levels are ongoing and improvements to the current design are expected.

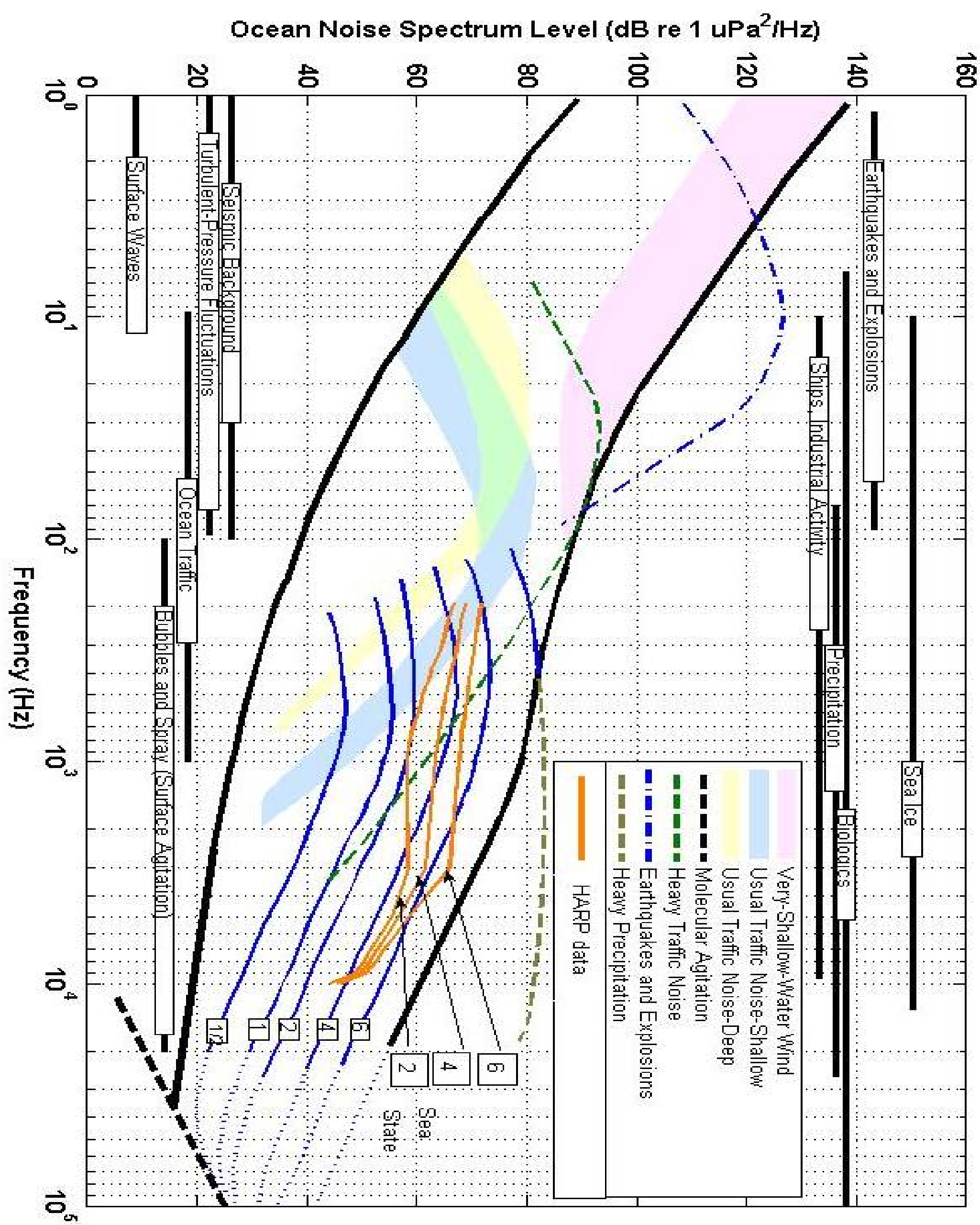

Figure 8. 2007 HARP ocean noise data (orange) for a given sea state plotted on Wenz (1962) curves

C. DIEL PATTERNS OF AMBIENT NOISE

Diel patterns of ocean noise may exist due to biological, meteorological, or even anthropogenic sources. Determining the causes for and the character of diel trends in ocean noise is useful not only from an ASW perspective, but can be important in the study and monitoring of marine life.

To determine if a diel pattern existed in the ambient noise recordings, the hourly averaged pressure spectrum level at 313 Hz was plotted for each month (Figure 9). McDonald et al. (2006) made a similar analysis at 315 Hz for a site west of San Nicolas Island, California. The data from 2003-2004 was compared to data from Wenz (1968) (Figure 10). The 1964-1965 data showed 2-4 dB diel variation in the ambient noise with peak energy during the hours of darkness. The diel variation was absent in Point Sur data as well as the 2003-2004 San Nicolas Island data.

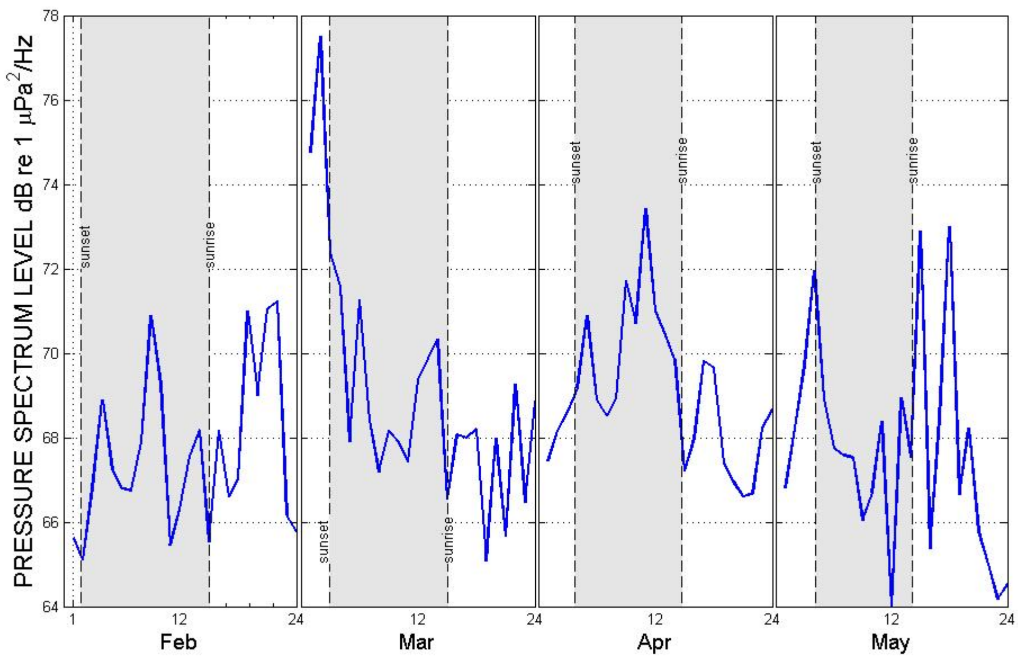

Figure 9. Pt. Sur monthly averaged pressure spectrum levels at 313 Hz, plotted vs. time of day (in GMT).

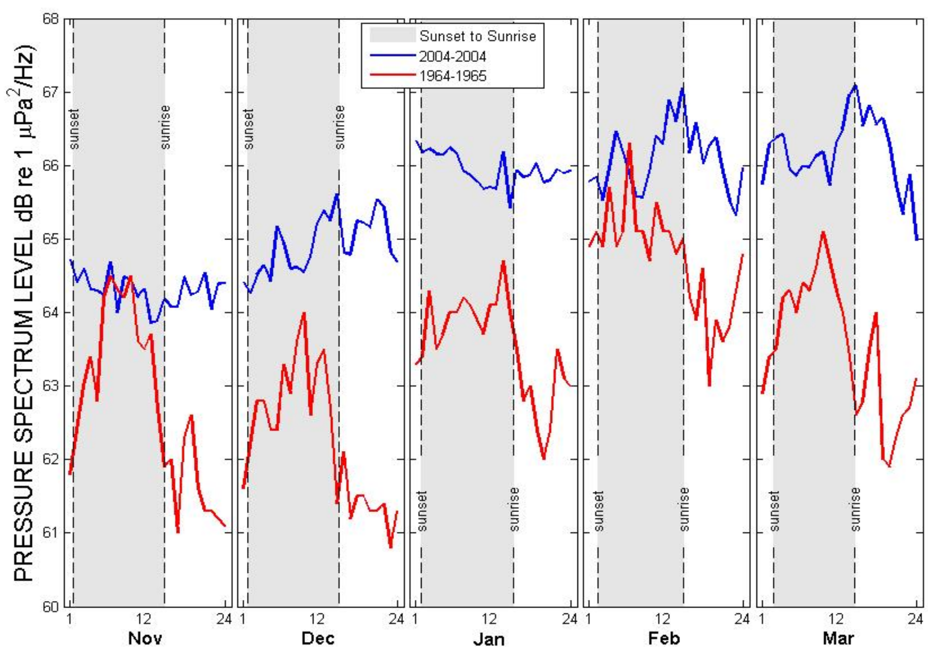

Figure 10. San Nicolas Island monthly averaged pressure spectrum levels at 315 Hz, plotted vs. time of day (in GMT). [From McDonald et al., 2006]

The HARP deployment site at Point Sur is significantly different than the San Nicolas Island site. A major shipping lane is located near the Point Sur site while the San Nicolas site is outside major shipping lanes and is located in a naval weapons range, which is intermittently closed to traffic. Thus, the higher average sound levels at Point Sur were as expected.

Transients due to nearby ships that were greater than 3 dB above ambient noise were removed from the Wenz (1968) data, but not from McDonald et al. (2006) or the data obtained from Point Sur. The removal of the transients amounted to less than a 1 dB change in the overall average (McDonald et al. 2006). It is likely that removing these transients from the Point Sur data would have changed the averages by a greater amount than what was observed by Wenz (1968). In addition to the ship traffic noise, sound from biologics was a major contribution to the elevated energy levels.

The monthly averaged HARP data had several maxima that were up to 10 dB higher than the mean value. To determine the causes of these spikes in energy level, the 112 data points (16 recordings per hour times 7 days) that comprised the monthly average were plotted against time. The recorded segments with high sound levels were, in every case, associated with a common event and indicated a nearby source. Each recording was then played audibly and the source of each elevated grouping of sound was confirmed to be due to either a passing ship or biologics. The spike that occured in April at 1000 GMT in Figure 9 was shown as an example (Figure 11). Based upon the amplitudes of the recorded sound, it was observed that biologics influenced the level of background noise as much as passing ships.

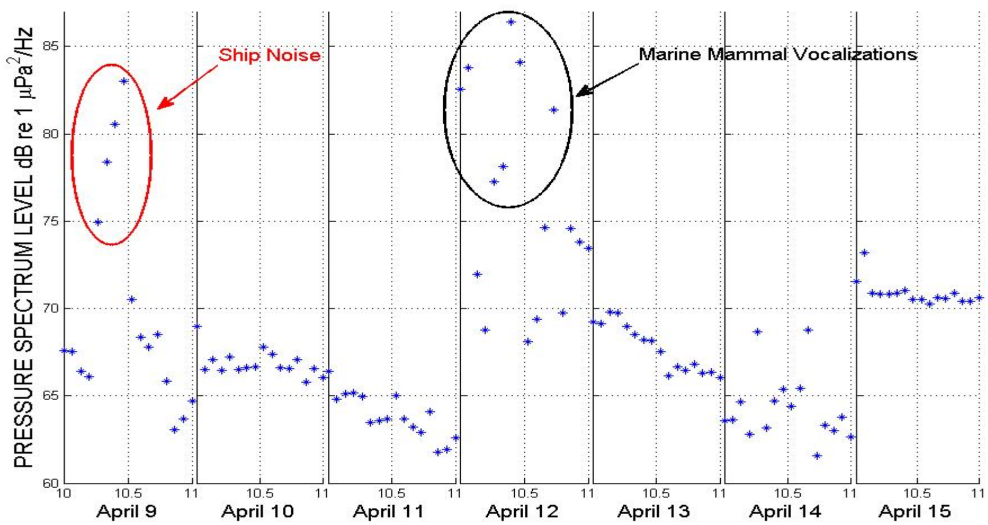

Figure 11. Scatter plot of pressure spectrum level at Pt. Sur vs. the same hour of day for a week in April. Each data point represents an averaged level over a time span of 10 seconds. The instances of ship noise and marine mammal vocalizations were verified through audio playback.

D. SHIPPING NOISE

In order to accurately predict ambient noise levels at various locations, it is clearly necessary to have an understanding of the local shipping activity. The current trend of increasing littoral applications of ASW results in employing acoustic sensors in areas of higher traffic densities and thus higher and more variable noise levels. In an attempt to better understand the shipping traffic contribution to noise, the shipping density from the San Francisco Bay Area and the Los Angeles/Long Beach harbors were compared to the Point Sur data. Since noise from ships has been found to affect noise in the 10 to 1000 Hz frequency band (Wenz 1962), several frequencies in this range were chosen for analysis.

As mentioned earlier, the shipping data included four groups; San Francisco arrivals from the south, San Francisco departures to the south, Los Angeles-Long Beach arrivals from the north, and Los Angeles-Long Beach departures to the north. There major difficulty in comparing these shipping data to the Pt. Sur noise data was that they were not collocated, e.g. the transit time from arrival or departure at San Francisco or Los Angeles-Long Beach to Pt. Sur was not known. Rather than assume a constant transient time for each ship, each arrival or departure was considered an ‘event’ and grouped together by the date of occurrence. Thus, two events which were classified the same may have occurred a day or more apart at Point Sur. Therefore, the correlation between time series of ocean noise and shipping traffic was not expected to yield high values.

To achieve the maximum possible correlation for these shipping data, the time series for each category was shifted zero, one, or two days. Since ships arriving at port would pass near the HARP mooring location prior to the date on which they were reported as arriving, the time series for arrivals were shifted back one and two days, and the opposite is true for departures. Adding the four groups of shipping data with the various lag times resulted in 81 combinations. The cross-covariance of daily averaged ocean noise with each of the combinations of shipping traffic data was then computed.

Upon plotting the correlation coefficient at zero lag for each of the 81 combinations of shipping traffic data, a clear pattern was observed. Since the location of the HARP mooring was physically closer to San Francisco, the combinations of the San Francisco data had a greater affect on the values of correlation over all frequencies analyzed. It is interesting to note, however, that the same combination of San Francisco data did not result in the highest values of correlation coefficient over all frequencies. At frequencies below 200 Hz, the highest correlation coefficients at zero lag were obtained by using the San Francisco arrivals with a shift of one day and no adjustments to the departure time series. Between 200 and 300 Hz, the highest correlation values came from the San Francisco arrivals with an adjustment of two days and no adjustment to the departure time series. Above 300 Hz, the maximum values of correlation were achieved without any shift in the San Francisco data. In general, shifting the Los Angeles-Long Beach arrivals and departures both by two days resulted in higher values of the correlation coefficient, but the trend did not hold true for all frequencies and in any case, was not nearly as important as the combination of the San Francisco data.

Frequency (Hz)	Correlation Coefficient	Best Combination of Shipping Data
39	0.425	LA2+LD2+SA0+SD2
78	0.262	LA2+LD2+SA1+SD0
117	0.301	LA2+LD2+SA1+SD0
156	0.338	LA2+LD2+SA1+SD1
195	0.331	LA2+LD2+SA1+SD0
234	0.309	LA1+LD2+SA2+SD0
273	0.310	LA0+LD2+SA2+SD0
312	0.311	LA1+LD1+SA2+SD0
508	0.433	LA1+LD1+SA0+SD0
703	0.546	LA0+LD2+SA0+SD0
977	0.493	LA0+LD2+SA0+SD0

Table 1. Correlation coefficients at zero lag for various frequencies and shipping traffic data combinations. L stands for Los Angeles-Long Beach. S is for San Francisco. A and D stand for arrivals and departures, respectively. The number indicates how many days the time series was shifted. For example, LA2 represents the Los Angeles-Long Beach ship arrival time series that is shifted back two days. SD1 represents the San Francisco departure data which is shifted forward one day.

The values of the correlation coefficients were weak to moderate in all cases. This was not unexpected. A contributing factor to the low correlation values was the presence of marine mammal vocalizations at the frequencies analyzed. Perhaps the main reason for the low correlations was that not every ship which contributed to noise recorded by the HARP was accounted for in the shipping data utilized. The San Francisco and Los Angeles-Long Beach data were selected because it was expected that the data from these two ports would contain a significant percentage of ships transiting the West Coast and therefore have the largest impact on local noise. However, there were many ships that passed near the hydrophone that neither arrived nor departed the aforementioned ports. The presence of noise from these ships in the HARP recordings, but not accounted for in the shipping time series, further reduced the correlation coefficients.

The correlation coefficients tend to increase with frequency. This is consistent with the predominately shorter range, higher angle, and direct path arrival of sound which is expected as ships pass near the HARP mooring. The lower frequencies are attenuated less and travel farther. Therefore, low frequency sources at greater ranges would have an impact on ambient noise and would lower the correlation. For this reason, the ships that were not included in the San Francisco and Los Angeles-Long beach data, and the ships that arrived or departed westward from these ports, would contribute to decreasing correlation in lower frequencies. Since the distance between Point Sur and San Francisco is relatively small (about 100 nm), ships departing San Francisco to the north may also have had an impact on the recorded noise and thus affected the correlations. Additionally, low frequency noise from distant sources would be propagation path dependent and experience greater variability due to bathymetry and water column conditions changing as a function of range and angle relative to the receiver.

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IV. CONCLUSIONS AND RECOMMENDATIONS

A. AMBIENT NOISE

The measurements and comparisons presented in this study indicate the HARP recordings are useful for studies of ambient noise. Since effective ASW hinges on the ability to properly predict background noise levels, continued study of HARP recordings at Pt. Sur and other Navy operational areas is recommended. In the endeavor for a more complete understanding of the factors and trends which affect ambient noise levels, the HARP has the capability to be an important tool.

1. Wind Noise

As expected, at Pt. Sur the wind speed had a significant (correlation coefficient above 0.5) impact on ambient noise above 400 Hz. An earlier study (Wenz 1969) indicated the primary cause of ambient noise shifted from shipping noise to wind noise at 200 Hz. McDonald et al. (2006) hypothesized that this breakpoint frequency has shifted upward due to the increase in the gross tonnage of ships at sea and the increased time each ship spends at sea due to faster port turn-around time. Analysis of the Pt. Sur HARP data supported the results of McDonald et al. (2006).

2. Shipping Noise

In an attempt to relate ambient noise to port activity, several combinations of arrival and departure data, along with various time lags, were explored in this study. Although there was no individual combination that resulted in the best correlation over the frequency band of 10 Hz to 1000 Hz, a clear pattern existed within frequency bands. Bathymetry and depth of water, as well as the proximity to shipping channels and ports, influence both the noise level and frequency detected for a given sensor location.

B. SENSOR DESIGN AND PERFORMANCE

Based on the analysis presented in this paper, the HARP has proven to be a valuable sensor to utilize for acoustic research. At this stage, the main hindrances to optimal performance include excessive system noise and hydrophone sensitivity in frequencies above 2 kHz. However, as the design is new and refinement in sensor design and performance continues, improvements to performance are expected in the near future.

Most of the excessive system noise present in the recorded data was caused as the disk drives were activated in the disk writing process. The circuitry located inside the pressure case contains no shielding. Either the vibration from the spinning disks or electromagnetic radiation from the disk drives was presumed to be coupled to the output of the hydrophone prior to noise whitening and amplification. Proper shielding of the input signal may help to alleviate the system noise from contaminating the recorded data.

The hydrophone design consists of two separate stages of signal conditioning. One covers the frequency band from 10 Hz to 2000 Hz and the other from 1000 Hz to 100,000 Hz

(Wiggins and Hildebrand 2007). For the higher frequency band, hydrophone sensitivity was sacrificed for a better response shape since change in ambient ocean noise with frequency is typically large at frequencies above 1000 Hz. It is likely the true ambient noise floor at the higher frequencies were not being recorded due to the inadequate hydrophone sensitivity levels. This problem may have prevented wide spread use of the sensor in continued studies to characterize high frequency ocean ambient noise. However, the architects of this system are fully aware of this issue and are currently testing a solution (Wiggins 2008).

C. FUTURE WORK

1. Location of Sensor

The decision was made to deploy the HARP adjacent to the old SOSUS hydrophone array so that the ability existed to conduct direct comparisons with earlier work at the same location and thus provide a benchmark to validate sensor performance. While this justification was warranted and the comparisons were made and should continue to be made, changing HARP deployment location for future acoustic data collecting is recommended. As deployed in this study, the HARP was moored on the westward, downhill side of an undersea ridge. To the east of the ridge is a northbound shipping track. It is therefore likely that the HARP hydrophone is in a shadow zone created by the ridge and that the acoustic data collected does not accurately reflect the actual shipping density.

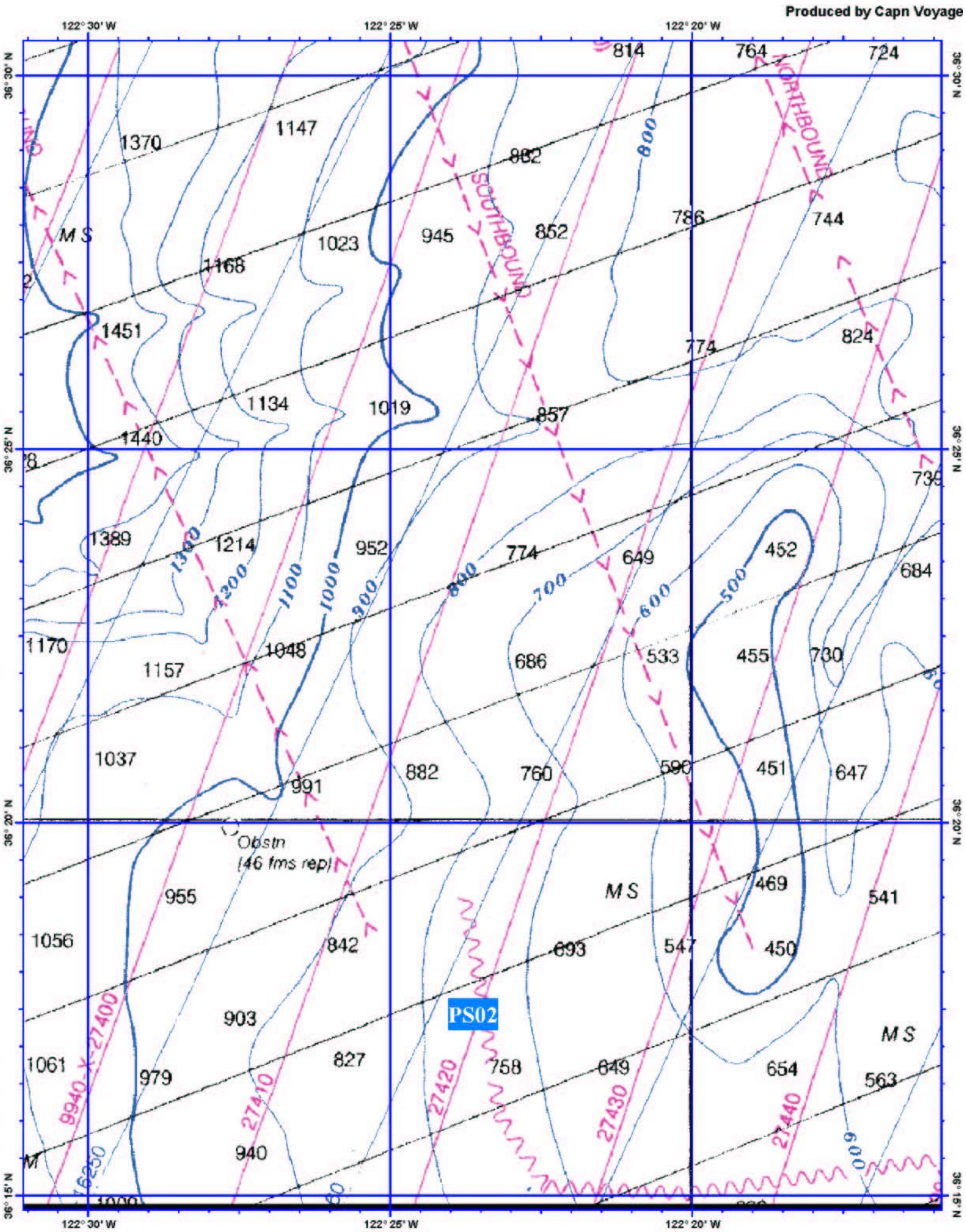

Figure 12. Portion of NOAA chart 18022. Sound from vessels in transit along the northbound track may be blocked by the undersea ridge shown. The HARP mooring (labeled PS02) is likely in an acoustic shadow zone caused by the ridge.

2. Measurements of Wind Speed

Measurements of wind stress were available from two local buoys, one maintained by NOAA and the other by the Monterey Bay Aquarium Research Institute. These data were of high quality and useful for comparison with ocean acoustic recordings. In considering locations for future HARP deployments, the availability of direct measurements of wind stress must be considered.

3. Measurements of Ship Traffic

The ship traffic data available for this study were of limited utility. It is recommended that future studies try to collect information on ship traffic near the HARP site. This can be done for most coastal sites by use of automatic vessel identification systems (AIS) which are currently required on all non-naval vessels greater than 500 tons. Note that the Department of Homeland Security has proposed that use of AIS be extended to all vessels which are 50 ft. in length or greater; if this requirement is adopted, detailed coastal studies of the effects of ship traffic on ambient noise would be possible.

4. Final Remarks

The wind and shipping related noise comparisons in this study were made without attempting to remove noise transients in the data resulting from nearby sound sources. In one study (McDonald et al. 2006), it was reported that removing the transients resulted in less than a 1 dB change in the overall average noise level. Since the HARP mooring was located near several shipping lanes, future analysis of the HARP noise recordings with the transients removed should be compared with this work to determine the effect of local noise.

The broad frequency range and low power, high data capacity features of the HARP make it a valuable tool for a wide variety of acoustic research studies. The HARP is already proving to be a valuable tool in the study of marine mammals and other sea life. As the current limitations in hydrophone sensitivity become resolved, proper analysis of recorded data could have a dramatic affect in the ability to predict ambient ocean noise, and in turn, on the effectiveness of conducting ASW missions.

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